AD-A137 603 STUDIES OF THE PROPAGATION OF ELASTIC WAVES IN FLUIDS AND SOLIDS(U) JOHN CARROLL UNIV CLEVELAND OH DEPT OF PHYSICS E F CAROME 15 DEC 83 N00014-75-C-0247 1/1

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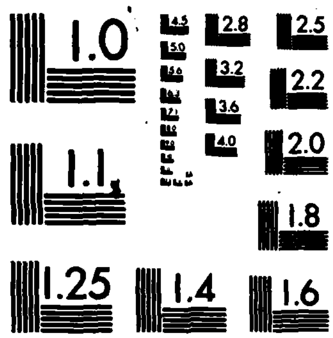

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A137603
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) STUDIES OF THE PROPAGATION OF ELASTIC WAVES IN FLUIDS AND SOLIDS.	5. TYPE OF REPORT & PERIOD COVERED Final Report: 1 December 1974 to 30 November 1983
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Edward F. Carome	8. CONTRACT OR GRANT NUMBER(s) ONR Contract N00014-75-C-0247
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Physics, John Carroll University, Cleveland, OH 44114	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NR 384-309
11. CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research, Physics Division Office, Arlington, VA 22217	12. REPORT DATE December 15, 1983
	13. NUMBER OF PAGES 13 pages (include cover pg. & documentation pg)
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Same as 11	15. SECURITY CLASS. (of this report) Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE NA

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

Same as 16

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18. SUPPLEMENTARY NOTES

None

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Ultrasonics; acoustic transients; acousto-optic effects; fiber optic sensors; thermal phonons; polyvinylidene fluoride; acoustic impulses; elastic waves in solids; elastic waves in liquids; scattering of acoustic waves.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This final report outlines research in physical acoustics performed in the Physics Department of John Carroll University during the period 1 December 1974 to 30 November 1983, under ONR Contract N00014-75-C-0247. The overall goals of this research and the various projects conducted are outlined. The latter included studies of fluids in the vicinity of the critical point; studies of thermal phonon propagation in single crystals; acoustic impulse generation, propagation and scattering studies; and basic research and (Over)

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S/N 0102-LF-014-6601

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development work on fiber optic acoustic sensor systems. Also included in this report are a list of publications resulting from the contract research and a list of graduate students who participated in the program, including the titles of their theses.

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FINAL REPORT

to the

OFFICE OF NAVAL RESEARCH

on

ONR Contract N00014-75-C-0247

STUDIES OF THE PROPAGATION OF ELASTIC WAVES IN FLUIDS AND SOLIDS

1 December 1974 to 30 November 1983

Department of Physics
John Carroll University
Cleveland, Ohio 44118

15 December 1983

INTRODUCTION

During the nine year period 1 December 1974 to 30 November 1983 the Acoustics Branch of the Office of Naval Research partially supported an extensive physical acoustics research program in the Department of Physics of John Carroll University. This research was conducted under ONR Contract N00014-75-C-0247 and was directed by Dr. Edward F. Carome, Professor of Physics. The long range goals of this program, some of its accomplishments, and the various research projects that were conducted with ONR support are outlined in this report. Also included are a list of publications resulting from the contract research and a list of graduate students who participated in the program, together with titles of their theses.

LONG RANGE GOALS

The ultimate goal of this physical acoustics research program had several important aspects. Scientifically its objectives were to obtain fundamental information about the structure of matter through studies of elastic wave propagation in gases, liquids and solids and, from a more applied point of view, to determine how the material properties and geometrical configurations of various systems affect the generation, propagation and reception of sonic and ultrasonic waves. Since this program was conducted within an academic institution it had the additional objective of educating physics majors in acoustics, as one of the important areas of physics. The University has recognized physical acoustics as a worthwhile area in which to excel. Over the past twenty-five years it has contributed to the steady expansion of the program, providing more than

10,000 square feet of modern laboratory space, substantial amounts of equipment and supplies, and more than adequate released time for faculty members.

AREAS OF RESEARCH AND ACCOMPLISHMENTS

The acoustics program supported by the contract was a very broad one. It included work in many different areas such as studies of the properties of gases, liquids, and solids by measurements of the velocity and absorption of sound in the kilohertz, megahertz, and gigahertz ranges; studies of diffraction and scattering of ultrasound; studies of the generation, propagation, and detection of acoustic transients, including laser induced pressure pulses; studies of the generation and detection of phonons in the fifty to five hundred gigahertz range using superconducting devices; and the discovery and investigation of acousto-optic interactions in optical fibers and the application of this phenomena in the development of various types of fiber optic transducers. It is appropriate to point out here that the current DOD Fiber Optic Sensor System (FOSS) Program arose out of cooperative research efforts, supported partially by this contract, between the Department of Physics of John Carroll University and the Physical Acoustics Branch of the Naval Research Laboratory.

In the following sections the research conducted in these various areas is briefly discussed. Detailed results are presented in the publications listed in this report.

1. Acoustic Studies of the Properties of Fluids in the Vicinity of the

Critical Point.

During the initial phase of this contract a long term study of the properties of simple fluids in the vicinity of the critical point was concluded. The final research in this area consisted of detailed measurements of the shear viscosity of carbon dioxide, sulfur hexafluoride and ethane. These were made using an acoustic resonator technique specifically developed for these critical point studies. The experimental data clearly show that there is an anomalous increase in the shear viscosity of simple fluids and indicated that in the low kilohertz range the functional form of the divergence is cusp-like in all three fluids. The results are consistent with the mode-mode coupling theory of Kadanoff and Swift and provided some of the first evidence of a universality in the behavior of the shear viscosity of simple fluids near the gas-liquid critical point.

2. Acoustic Studies of the Properties of Solids.

Research was done on the propagation of thermal phonons in the frequency range 50 to 300 gigahertz in crystalline solids at low temperatures. This involved extensive work on the development of very high frequency phonon generators and detectors, such as superconducting tunnel junction and fluorescent generators, and superconducting bolometers. These were used in experiments on the phonon propagation characteristics of various materials including high quality Al_2O_3 single crystals, and degenerate n-type InAs and InSb single crystals. The experiments were performed at temperatures between 1.6°K and 4.2°K where phonon propagation is ballistic. Constantin heaters and tin fluorescent generators were used as phonon generators and granular aluminum bolometers as detectors. Using this technique phonon scattering was studied over a wide range of input powers and pulse widths and the data fielded clear evidence of strong phonon-electron interactions in these two degenerate semiconductors.

A study also was made of acoustic absorption in uniaxially and biaxially stretched polyvinylidene fluoride PVF_2 polymer films over the frequency range 300 to 1500 MHz. Data were obtained at room temperature using a direct, continuous wave transmission-substitution technique. Within the precision of the measurements the absorption coefficient was the same for the various samples studied and was a linear function of the frequency ranging from 0.02 dB/micron at 300 MHz to 0.65 dB/micron at 1500 MHz. These measurements extended by almost a decade the frequency range over which such data were previously available.

3. Acoustic Impulse Studies.

The acoustic impulse technique developed under this and earlier ONR contracts was applied in a variety of projects. In cooperative studies with the Physical Acoustics Branch of the Naval Research Laboratory, for example, extensive research was done on diffraction effects and scattering of unipolar pressure impulse of widths as narrow as 0.1 μsec. Since they are well defined in both space and time such signals are ideally suited for resolving the various waves that may be generated when an acoustic wave is incident on an object submerged in water. Using both acoustic probe techniques and high resolution schlieren systems developed specifically for this work, extensive data were gathered on scattering by metal plates, solid cylinders and hollow shells. These experiments led to theoretical studies of schlieren image intensity distributions of unipolar acoustic pulses that established quantitative relationship between acoustic pressure amplitude and the corresponding schlieren images. The results have proved to be of great use in analyses of scattering by complex acoustic targets and in determinations of transducer transfer functions.

As an application of the impulse technique in the evaluation of transducer transfer functions it was employed as an efficient means to study the characteristics of new types of ultrasonic hydrophones. These were constructed using thin films of piezoelectrically active PVF_2 and included small diameter probes, linear elements, annular rings and other configurations. The experimental results indicate that such transducers can behave as broadband, non-intrusive, i.e., acoustically transparent, detectors of ultrasound in water and other liquids. The wide band acoustic pulses used to calibrate the various hydrophones were produced by driving thick PZT disks with monopolar electrical voltage pulses. It may be shown that the temporal form of the initial pressure pulse radiated into a water load is the same as that of the applied voltage. Thus the amplitude and phase response of an ultrasonic receiver can be found by deconvolution of the source transducer and receiver voltage pulses. This procedure was performed for the various hydrophone probes via fast Fourier transformations of the sampled incident and output waveforms. The results clearly showed that the 25 micron thick PVF_2 hydrophones have flat frequency response and linear phase response to well above 10 MHz, and that the group (phase) delay associated with the phase response is negligible.

Concepts developed in this phase of the research were employed in a study, partially supported under the contract, of a technique for generating bistatic and total field scattering patterns of submarines using monostatic target strength data. This technique was applied to target strength data for several submarine highlights obtained in sea test studies. A number of total field scattering patterns for the major horizontal plane of a submarine were developed and analyzed and the results appear to be meaningful. They clearly indicate that the technique should be of use in analyses of submarine detectibility, weapons scenarios and other underwater target problems.

4. Fiber Optic Sensor Studies.

The current NRL directed Fiber Optic Sensor System (FOSS) Program arose out of cooperative research efforts between the John Carroll Physics Department and the NRL Physical Acoustics Branch that were partially supported by this contract. Late in 1976 and during the first six months of 1977 the initial experiment that indicated the feasibility of an interferometric-type optical fiber acoustic sensor were carried out at John Carroll and at NRL. Based on the results of these experiments funding was obtained from DARPA and other DOD groups for the present multi-disciplinary FOSS program.

Research on various types of fiber optic acoustic sensors, including intensity as well as interferometric types, were continued at the University. An experimental study was made, for example, of an optical waveguide coupler-type acoustic sensor that employs multimode fibers. With LED optical sources this sensor behaves as an optical intensity modulation sensor with sensitivity of the order of 70 dB re 1 μPa. A study also was made of a dark field-type microbend sensor that employs graded index multimode fibers. Extensive work was done on the development of suitable fiber-to-fiber couplers to pick up bending-induced light transfered from core to cladding in this type of sensor. In addition to this work on optical fiber acoustic sensors other related studies were made of acousto-optic interactions in optical fibers and other effects of interest in fiber sensor work.

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GRADUATE STUDENTS WHO RECEIVED PARTIAL SUPPORT UNDER THE CONTRACT AND THEIR THESIS TITLES

1975

Linda C. Burke
"Surface Waves Generated on Liquid Solid Interfaces by Laser-Induced Acoustic Pulses."

Michael R. Fisch
"An Experimental Study of the Shear Viscosity of Simple Fluids in the Critical Region."

Thomas T. Long
"The Preparation and Use of Thin Film Devices for the Generation and Detection of Phonons in Sapphire."

Leon J. Miernicki
"An Experimental Study of the Transition Region Operating Curves of a Superconducting Thin Film Bolometer."

1976

Mary Beth Abele
"Shear Viscosity Measurements of a Critical Liquid Mixture."

Lynn A. Blyth
"The Use of Gold-Seeded Tin Superconducting Bolometers in the Detection of High Frequency Phonons in Semiconductors."

Alan Ivons
"A Low Temperature Study of Electromagnetic Generation of Ultrasound in Magnesium."

Thomas J. Langill
"Frequency and Mean Free Path Dependence of the Ultrasonic Attenuation in Potassium Using an Oblique Magnetic Field Technique."

Joseph J. Ursic
"Scattering of Acoustical Impulses from Liquid-Solid Interfaces."

1977

Brian D. Hunt
"The Cutoff in the Electron-Phonon Interaction in Indium Arsenide."

Michael R. Layton
"Short-Wavelength Backscattering from Thin Spherical Shells."

1978

Michael P. Satyshur
"An Experimental Study of Optical Fiber Sound Sensors."

1979

Gary S. Chulick
"Sampling and Computer Processing System for High Frequency Waveforms."

Peter B. Schmidt
"An Experimental Study of Amplitude Modulation in Optical Fibers."

Carl E. Walz
"Ballistic Phonon Scattering in InAs and Al_2O_3."

1980

Charles W. Allen
"The Excitation of Acoustic Modes in Metal Cylindrical Shells by Means of PVF_2 Transducers."

1981

Robert Joseph Hauenstein
"Phonon Scattering Studies in y-LiF."

Daniel Arthur Young
"The Interaction of Ballistic Phonons in a Heat Pulse with Electrons in InSb."

1982

Clarence J. Zarobila
"Single Microbend-Induced Power Loss in a Corning@ Type 4002D Parabolic Index Optical Fiber."

1983

John G. Eustace
"Diffraction of Light by Acoustic Waves on a Mylar Film."

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